

Coupling biogeochemical cycles in urban environments: ecosystem services, green solutions, and misconceptions

Diane E Pataki^{1,2*}, Margaret M Carneiro³, Jennifer Cherrier⁴, Nancy E Grulke⁵, Viniere Jennings⁶, Stephanie Pincetl⁷, Richard V Pouyat⁸, Thomas H Whitlow⁹, and Wayne C Zipperer⁶

Urban green space is purported to offset greenhouse-gas (GHG) emissions, remove air and water pollutants, cool local climate, and improve public health. To use these services, municipalities have focused efforts on designing and implementing ecosystem-services-based "green infrastructure" in urban environments. In some cases the environmental benefits of this infrastructure have been well documented, but they are often unclear, unquantified, and/or outweighed by potential costs. Quantifying biogeochemical processes in urban green infrastructure can improve our understanding of urban ecosystem services and disservices (negative or unintended consequences) resulting from designed urban green spaces. Here we propose a framework to integrate biogeochemical processes into designing, implementing, and evaluating the net effectiveness of green infrastructure, and provide examples for GHG mitigation, stormwater runoff mitigation, and improvements in air quality and health.

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Humans are increasingly influencing biogeochemical cycles at a global scale (Vitousek et al. 1997; Rojstacster et al. 2001). From the publication of "man's role in changing the face of the Earth" (Thomas 1956) to the recent syntheses on climate change (eg Solomon et al.

2007), the role of cities in altered biogeochemical cycles has received increasing attention; for the first time in human history, more people live in urban areas than in the countryside (UN 2010). As cities concentrate increasing numbers of people, they also concentrate and transform energy, materials, and waste in small areas. Although constraining populations to smaller areas may have advantages for land and other resource uses (Anderson et al. 1996), techniques and approaches need to be developed to design more efficient and sustainable cities.

One approach to improving urban sustainability is to use "ecosystem services" to remediate pollution and other environmental problems (McPherson et al. 1998; Boland and Hunhammar 1999; Nowak et al. 2002; McPherson et al. 2005; Oberndorfer et al. 2007). The Millennium Ecosystem Assessment (MA 2003) provided a framework for categorizing the societal benefits of ecosystems into different services: provisioning services (which provide food and materials), cultural services (which provide aesthetic and psychological benefits), and regulating services (which moderate environmental conditions and quality; Figure 1). Each of these services relies on fundamental ecological processes that are recognizable and in most cases measurable by members of the scientific community. Here we focus on the climate-, water-, and atmosphere-regulating services provided by planned urban green space, including but not limited to urban forests, parks, and gardens. Regulating services in green space are intimately linked to many fundamental biogeochemical processes, which are the biological and chemical processes that cycle and transform carbon (C), nutrients (eg nitrogen [N] and phosphorus [P]), water, and other materials in the environment.

There is a growing body of literature about the poten-

In a nutshell:

- Many commonly cited environmental benefits of urban greenspace are still poorly supported by empirical evidence, adding to the difficulties in designing and implementing green infrastructure programs.
- To date, there is little data showing that urban greenspace can reduce urban greenhouse-gas emissions or air and water pollutant concentrations.
- There is evidence to support substantial reductions in urban runoff, local atmospheric cooling, and improvements in human health that do not appear to be related to pollutant concentrations.
- Studies of urban biogeochemistry are greatly needed to improve greenspace design and monitor its effectiveness in meeting local environmental goals in different regions and urban settings.

¹Department of Earth System Science, University of California, Irvine, Irvine, CA; ²Department of Ecology & Evolutionary Biology, University of California, Irvine, Irvine, CA (dpataki@uci.edu); ³Department of Biology, University of Louisville, Louisville, KY; ⁴Environmental Sciences Institute, Florida A&M University, Tallahassee, FL; ⁵Pacific Southwest Research Station, USDA Forest Service, Riverside, CA; ⁶Southern Research Station, USDA Forest Service, Gainesville, FL; ⁷Institute of the Environmental and Sustainability, University of California, Los Angeles, Los Angeles, CA; ⁸USDA Forest Service, Washington, DC; ⁹Department of Horticulture, Cornell University, Ithaca, NY

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